the Ring nebula in *Lyra*, with the 36 inch refractor. The Crossley photographs show that it is a left-handed, two-branched spiral, with an extreme diameter of about 30″.

The Ring Nebula in Cygnus (G. C. 4565).—This is a nearly circular nebula, only about half the size of the one in *Lyra*, and very much fainter. There is a drawing by Sir JOHN HERSCHEL in the *Philosophical Transactions* (1833),* in which the nebula is represented as a faint ring without detail, and one by Lord ROSSE,† in which the faint nebulosity within the ring is also shown. I do not know of any other published drawings or of any photographs whatever.

Two photographs of this nebula were made with the Crossley reflector in August of the present year, and from one of them, to which an exposure of two hours was given, enlargements were made in the manner already described.

As shown on the photographs, the nebula is a nearly circular ring, measuring 42″.5 by 40″.5. The outer boundary is fairly sharp. On the inside of the ring the brightness fades somewhat gradually toward the center, which is marked by a nucleus, or star, of about the sixteenth magnitude. At several places, narrow streaks of nebulosity project from the inner edge of the ring, part way to the center, like imperfect spokes. One bright star (14.5 mag.) is shown on the ring. It was observed by Lord ROSSE. There is no evidence that this star is physically connected with the nebula, and its position on the ring is probably an accidental effect of projection. The nebula is surrounded by small stars, the distances and directions of which from the central nucleus have been measured on the photographs, in order that any proper motion of the nebula may be detected by repeating these observations at some time in the future.

THE RISE AND PROGRESS OF ASTRONOMY IN CENTRAL EUROPE.—III.

By SIDNEY D. TOWNLEY.

Although without a rival as a practical astronomer, still TYCHO BRAHE was not without contemporaries. The science of astronomy was being advanced by a few persons in Germany, chief

* Plate XIII, fig. 48. † Observations of Nebulæ and Clusters of Stars, Plate V.

among whom may be mentioned WILLIAM IV, Landgrave of Hesse (1532 to 1592).

Even before TYCHO he perceived that astronomy needed above all accurate observations. His observatory, in Cassel, was a tower on the Zwehrer Thor. The tower was surmounted by a revolving dome; and this was, as far as known, the first time this now generally adopted device was used. Observations were made by the Landgrave from 1516 to 1567; but in the latter year the government of the province fell upon him, and but little observing could be done thereafter.

Later, ROTHMANN, a mathematician, and BUERGI, an expert clockmaker, were engaged by the Landgrave to carry on the observing. Through a pupil of TYCHO'S they learned of the improvements made in the instruments at Uraniaborg, and immediately adopted many of them. Clocks were extensively used by these observers, and in that practice their methods differed materially from TYCHO'S. Their observations were made chiefly upon the fixed stars, the intention being to form a catalogue of over a thousand stars. The work, however, was never completed, as it was soon given up after the death of the Landgrave, in 1592. BUERGI was a very ingenious person, and is said to have used logarithms and applied the pendulum to regulate the running of a clock. Neither of these discoveries, however, was given to the world.

Many students came to TYCHO to act as his assistants, but of these one only achieved fame. JOHN KEPLER (1571 to 1630) was born at Weil, in Wurtemberg. Reared in poverty, he was nevertheless able, being a born scholar, to obtain a university education. He attended the University of Tuebingen, and it was while a student there that he obtained his first knowledge of astronomy, through the teaching of MOESTLIN, professor of mathematics. KEPLER'S studies, however, were mostly along the line of metaphysics and theology, and it was therefore with reluctance that he accepted a lectureship in mathematics at Gratz in 1594.

Being of a very imaginative and speculative turn of mind, one of the first questions that troubled KEPLER was concerning the causes of the number, size, and motion of the planets. He attempted first to establish a relation between the distances of the planets from the Sun. After working along many lines, he happened to remember that there were only five regular solids, and

these he thought might be connected in some way with the five spaces between the six planets then known. He finally evolved the following: the orbit of the Earth was represented by a sphere; about this a dodecahedron was circumscribed; and around that another sphere, which gave the orbit of *Mars;* around that a tetrahedron was placed, the corners of which mark the sphere of the orbit of *Jupiter;* around that sphere again a cube was placed which roughly gave the orbit of *Saturn.* In the inside of the sphere of the earth an icosahedron was inscribed, and inside the sphere of that an octahedron, and the spheres of these two represented the orbits of *Venus* and *Mercury.*

The result of these labors, together with an account of all the unsuccessful attempts, was published by KEPLER in a work called *Mysterium Cosmographicum.* I mention it not from the intrinsic value of the work, but because a copy of it was sent to TYCHO BRAHE, who recognized the genius of the author and wrote a letter to KEPLER, thus beginning the acquaintance which in after years led to results of such momentous importance to the science of astronomy.

TYCHO gave KEPLER this sound advice: "To lay a solid foundation for his views by actual observation, and then, ascending from these, to strive to reach the causes of things."

In 1601, KEPLER was made Imperial Mathematician by the Emperor RUDOLPH II, on condition that he should assist TYCHO BRAHE in Prague. It was TYCHO's intention to construct tables of the Sun, Moon, and planets, founded on his own observations. His end came, however, before the work was fairly commenced, and on his deathbed he intrusted the task to KEPLER, with the request that the tables be called after their benefactor, RUDOLPH. Upon the death of the master, the assistants, with the exception of KEPLER, soon went away. KEPLER was appointed to TYCHO's position, and the great mass of observations accumulated by that brilliant observer fell into KEPLER's hands. They could not have fallen into worthier ones. Every one knows the three famous laws brought forth from them. As long as the science of astronomy shall exist they will stand as an imperishable monument to the genius of JOHN KEPLER.

It is not my purpose to enter into the details of the labors by which KEPLER arrived at these results. They were derived from investigations of the motion of the planet *Mars*, this planet being chosen on account of the large eccentricity of its orbit and the

large number of observations which TYCHO had made upon it. His method was to suppose some theory of motion, then to calculate the positions of *Mars* according to this theory, and see if the positions agreed with TYCHO's observed places. For a long time he held to the idea of circular motion. Hundreds of different suppositions were tried, and each thrown aside when it was found not to agree with TYCHO's observations. As logarithms were not then invented, we can easily imagine the tremendous labor necessary to carry out these calculations. Years were spent in this work; and we hardly know which to admire more — the genius to think out the theories, or the patience to carry out the culculations.

After years of labor, he finally gave up the idea of uniform circular motion. That seems to us an easy thing to do; but we must remember that at that time scholars' minds were still enslaved by the philosophy of ARISTOTLE, and according to that philosophy circular motion was the only perfect motion, as it would be impossible for the planets to move in any other way. KEPLER thought first to try a variable circular motion, and to facilitate the computations divided the orbit into sectors, and the second law was almost immediately found, namely, that the radius-vector describes equal areas in equal times. This result aroused great enthusiasm in him; but comparison with TYCHO'S observations soon showed that it was not sufficient. KEPLER announced this in the following quaint way: "While thus triumphing over *Mars*, and preparing for him, as for one already vanquished, tabular prisms and equated eccentric fetters, it is buzzed here and there that the victory is in vain, and that the war is raging anew as violently as before. For the enemy left at home a despised captive has burst all the chains of the equations, and broken forth from the prisms of the tables."

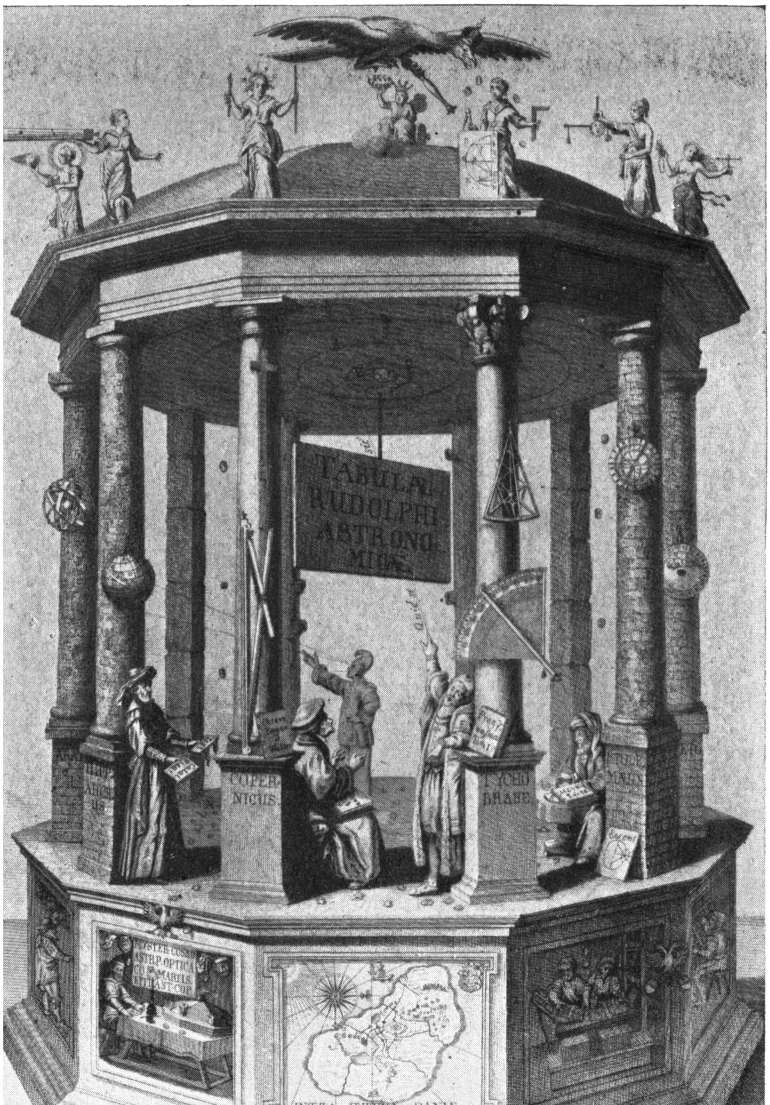
KEPLER'S next effort was to try an oval for the orbit. Various kinds were tried, but it then transpired that the law already found did not hold true. Finally the ellipse was tried, and KEPLER found to his great delight that when the Sun was placed at one focus the first law still held, and the places agreed with those observed by TYCHO BRAHE within the unavoidable errors of observation. Hence the result: the orbit of *Mars* is an ellipse with the Sun at one focus. The complicated system of epicycle, equant, deferent, eccentric, and so forth, was swept away forever.

The first two laws were published in 1609, in his greatest work, *Astronomia nova de motibus stellæ Martis ex-observationibus Tychonus Brahe*, generally designated by the title, "Commentaries on the Motions of *Mars*." Still KEPLER was not satisfied, but kept thinking over the idea that he had long held, that there must be some connection between the distances of the planets and the times of their revolution. After several years of thinking and calculating, the third law was finally evolved, namely, the squares of the times of revolution of the planets about the Sun are proportional to cubes of their mean distances from the Sun. This law was published in 1619, in a work called *Harmonices Mundi* (Harmonies of the World).

Other important works were issued by KEPLER, chief among which may be mentioned *Epitome Astronomiæ Copernicanæ*, in 1621, and *Tabulæ Rudolphinæ*, in 1627. He prefaced the tables with a fanciful home of astronomy, which is here reproduced from FRISCH'S edition of KEPLER'S works (Vol. VI).

Thus in brief is an outline of the life and work of JOHN KEPLER. Although he held the high-sounding title of Imperial Mathematician, yet his salary consisted chiefly of promises, so that nearly his whole life was spent in extreme poverty. When we consider this fact, and also the fact that the man was afflicted with much illness and domestic trouble, we cannot look upon the stupendous labor performed and the brilliant results reached as anything short of marvelous. KEPLER was possessed of a most brilliant imagination and gave it full rein, but finally always tested a theory by comparing the results of it with TYCHO'S observations. These were held infallible, and any theory that did not agree with them was promptly abandoned, no matter how many years of trial it had cost.

One might suppose that a nature like KEPLER'S would be particularly open to the ideas and methods of astrology; but he is said to have entertained the greatest disgust for everything astrological in character. Still for many years, when it was impossible to get his salary paid, he published and sold an almanac in which were given weather predictions and astrological prognostications. Notwithstanding the many disappointments of his life, due to poverty, illness, and domestic troubles, he obtained great intellectual pleasure from his discoveries, as is witnessed by the following lines, written after the discovery of his third law: "What I prophesied two-and-twenty years ago, as



KEPLER'S "HOME OF ASTRONOMY."

soon as I discovered the five solids among the heavenly orbits,—which I firmly believed long before I had seen PTOLEMY'S *Harmonies*,—what I promised my friends in the title of this book, which I named before I was sure of my discovery,—what, sixteen years ago, I urged as a thing to be sought,—that for which I joined TYCHO BRAHE, for which I settled in Prague, for which I have devoted the best part of my life to astronomical contemplations,—at length I have brought to light, and recognized its truth beyond my most sanguine expectations. It is not eighteen months since I got the first glimpse of light, three months since the dawn, very few days since the unveiled Sun, most admirable to gaze upon, burst upon me. Nothing holds me; I will indulge my sacred fury; I will triumph over mankind by the honest confession that I have stolen the golden vases of the Egyptians to build up a tabernacle for my God far away from the confines of Egypt. If you forgive me, I rejoice; if you are angry, I can bear it; the die is cast, the book is written, to be read either now or by posterity, I care not which; it may well wait a century for a reader, as God has waited six thousand years for an observer."

While KEPLER was thus engaged in clearing away the rubbish that filled the solar system, an invention which was destined to exert a great influence on the progress of astronomy was placed before the world. The invention of the telescope marked a new departure in the methods of the practical astronomer. It is scarcely possible to overestimate the value of this invention. The telescope has become an indispensable part of nearly every astronomical instrument. All honor is therefore due the man who first gave the invention to the world, and who first employed the telescope as an instrument of astronomical research.

"It is a remarkable circumstance in the history of science, that astronomy should have been cultivated at the same time by three such distinguished men as TYCHO, KEPLER, and GALILEO. While TYCHO, in the fifty-fourth year of his age, was observing the heavens at Prague, KEPLER, only thirty years old, was applying his wild genius to the determination of the orbit of *Mars*, and GALILEO, at the age of thirty-six, was about to direct the telescope to the unexplored regions of space. The diversity of gifts which Providence assigned to these three philosophers was no less remarkable. TYCHO was destined to lay the foundation of modern astronomy by a vast series of accurate observations made with the largest and the finest instruments; it was the

proud lot of KEPLER to deduce the laws of the planetary orbits from the observations of his predecessors; while GALILEO enjoyed the more dazzling honor of discovering by the telescope new celestial bodies and new systems of worlds."*

GALILEO GALILEI (1564 to 1642) was born in Pisa. He early displayed rare qualities as a student and a fondness for experimentation. In the University of Pisa his fondness for mathematics asserted itself, and he soon deserted the study of medicine, which had been chosen for him by his father. At the age of twenty-six he was appointed to a professorship in mathematics in Pisa. After a short time he changed to a similar position in Padua, which was held for many years.

Although greatly interested in astronomy, especially the Copernican system, still his greatest work was in the line of mechanics. Here was an unbroken field — there was nothing to guide him. He was a pioneer in this direction. He created science out of chaos, and established the laws of motion which a few years later led to the celebrated discoveries of NEWTON. Important as this work of GALILEO'S was, in its relation to the determination of the actual motions of the heavenly bodies, still it is not my purpose to deal with it, but rather with his pioneer work with the telescope, which means so much to the progress of practical and observational astronomy.

Still of this it is perhaps hardly necessary to write in any detail, for the story is familiar to every student of astronomy. It was in 1609 that GALILEO first heard of the invention, by a Dutch optician, of an instrument which made distant objects look near. He immediately set to work to reproduce the instrument, and soon accomplished the result by using a convexo-plane spectacle lens for an object-glass and a concavo-plane spectacle lens for an eye-piece. This magnified three times, and gave erect images, like opera-glasses of the present time; while the telescopes made by the Dutch opticians were of two convex lenses, and consequently gave inverted images. Soon afterwards an instrument that magnified ten times was made, and a little later one that gave a thirty-fold magnification. With this GALILEO examined the heavens, and a host of new things were at once revealed, — the mountains of the Moon, phases of *Venus* (as COPERNICUS had predicted), satellites of *Jupiter*, nebulæ, countless stars of the Milky Way, rings of *Saturn*, and spots on the Sun. These

* BREWSTER: "Martyrs of Science," p. 187.

indeed were great discoveries, and they added many arguments to the support of the Copernican theory, which was by no means as yet universally adopted. The telescopic discoveries of GALILEO were announced, in a history of astronomy, published in 1747 by GEORGE COSTARD, in the following quaint way:—

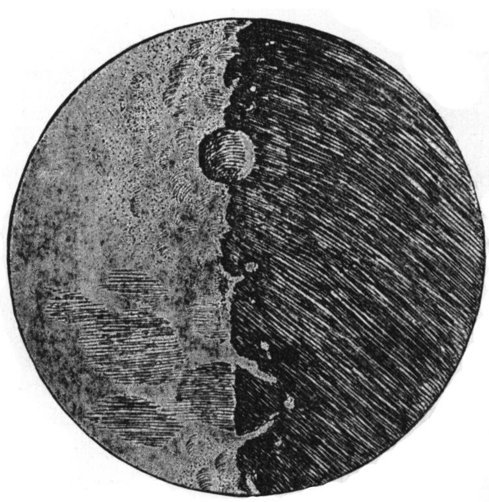
> GALILEO,
>
> who was the firſt that applied a Teleſcope to the Heavens, where he diſcovered the ſpots in the Sun, the four Satellites of *Jupiter* (called by him the *Medicean Stars*, in honour of the dukes of *Tuſcany*) and *Saturn* to be of a very ſtrange and uncouth figure.
>
> This laſt aroſe from the imperfection of Teleſcopes at that time, and the vaſt diſtance of *Saturn* from the *Sun* or *Earth*. . . .
>
> *Galileo* obſerved unevenneſſes in the Moon, like hills and vallies; and that the *Milky Way*, and *Nebulæ*, obſerved in ſome parts of the Heavens, as in the head of *Orion*, in *Cancer*, *&c.* are nothing more than a *congeries* of Stars, too ſmall to be ſeen by the naked eye.
>
> That the Moon is inhabited, and hath in it hills and vallies, is said to have been the opinion of *Anaxagoras*, about the year before Chriſt 480, as we ſaw before.
>
> But this could only be matter of conjecture, before the invention of Teleſcopes, or, perhaps, was aſſerted by him, as a conſequence of his other opinion, that the Sun and Moon were material; an opinion that had like to have coſt him his life. . . .
>
> *Galileo* obſerved, by means of his Teleſcope, that *Venus* did appear ſometimes horned like the Moon; and thereby verified the conjecture of *Copernicus*, and ſo far proved that his was the true Syſtem of the World.

The first object examined by GALILEO with a telescope was the Moon, and we reproduce on the next page his drawing of that object, together with one of sun-spots.* He published his telescopic discoveries in a little book under the title, *Nuncius Sidereus* (or the Sidereal Messenger).

These discoveries also gave GALILEO some new arguments against the Aristotelian philosophy, and in that way contributed perhaps more to the progress of learning than in any other. We must not forget that the tenets of the Aristotelian philosophy were

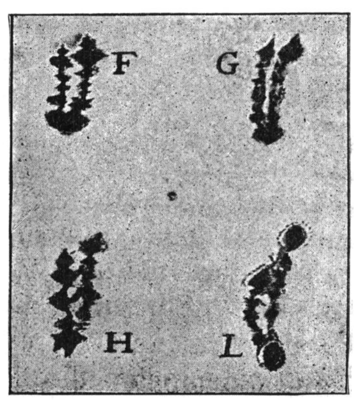
* These are copied from ARTHUR BERRY's new work, "A Short History of Astronomy."

still held to tenaciously, and persistently and fervently taught in all the universities. No one dared doubt the statements of that ancient sage, and it would have been philosophic heresy to test these long-established truths by simple experiments. GALILEO, however, was the exception to the rule, and some of his earliest experiments showed the falsity of some of the teachings of ARISTOTLE. Every one is familiar with his famous experiment of dropping two iron balls of different weights from the leaning tower of Pisa to demonstrate that the velocity with which a body descended did not depend upon its weight.



GALILEO'S DRAWING OF THE MOON.

GALILEO'S criticism and ridicule of the Aristotelian philosophy led him into many bitter controversies and made many enemies among his colleagues. Although a devout Christian, yet his espousal of the Copernican system eventually brought him into disfavor before the Church. In 1616, he was enjoined from teaching the obnoxious system; but in 1632, upon the publication of his famous "Dialogue on the Two Chief Systems of the World, the Ptolemaic and Copernican," the churchmen were thoroughly aroused, and GALILEO was summoned to appear before the Inquisition at Rome. It is not my purpose to review the details of the dreadful ordeal through



SUN-SPOTS — BY GALILEO.

which this martyr of science was obliged to pass. He sought only the truth. He was right, and his enemies were wrong, and he knew it as well as we do. To save himself from terrible torture and probable death at the stake, the old man at last recanted, declared the Copernican system to be false, and that the Earth did not move.

It has been stated, and quite generally believed, that GALILEO after recanting arose from his knees and said to a friend, "It does move, though." There is no probability whatever that he did say this, as is pointed out admirably by LODGE, in "Pioneers of Science": "Those who believe the story about his muttering to a friend, as he arose from his knees, '*E pur si muove*,' do not realize the scene. 1st, there was no friend in the place; 2d, it would have been fatally dangerous to mutter anything before such an assemblage; 3d, he was by this time an utterly broken and disgraced old man; wishful, of all things, to get away and hide himself and his miseries from the public gaze; probably with his senses deadened and stupefied by the mental sufferings he had undergone, and no longer able to think or care about anything, — except perhaps his daughter,— certainly not about any motion of this wretched earth."

We may now leave this poor old man. The balance of his life was spent in forced seclusion. Continual illness, grief, and finally blindness were added to his burdens. His enemies were triumphant. He fell, but the truths which he defended and then denied lived on. GALILEO'S contributions to astronomy were brilliant, but his contributions to mechanics were in many respects more remarkable. As before stated, he was a pioneer in this field, having inherited from his predecessors nothing but erroneous traditions and obscure ideas. His work in this line alone was sufficient to insure for him a high place among the scientific men of all ages.

"The scientific character of GALILEO, and his method of investigating truth, demand our warmest admiration. The number and ingenuity of his inventions, the brilliant discoveries which he made in the heavens, and the depth and beauty of his researches respecting the laws of motion, have gained him the admiration of every succeeding age, and have placed him next to NEWTON in the lists of original and inventive genius. To this high rank he was doubtless elevated by the inductive processes which he followed in all his inquiries. Under the sure guidance

of observation and experiment, he advanced to general laws; and if BACON had never lived, the student of nature would have found in the writings and labors of GALILEO, not only the boasted principles of the inductive philosophy, but also their practical application to the highest efforts of invention and discovery." *

(To be continued.)

ELEMENTS AND EPHEMERIS OF COMET *e*, 1899) (GIACOBINI).†

BY MISS A. HOBE, Y. KUNO, S. C. PHIPPS, AND ROGER SPRAGUE.

From the first three Mt. Hamilton observations by PERRINE, kindly telegraphed to the Students' Observatory by Director KEELER, Miss HOBE, and Messrs. KUNO and PHIPPS, advanced students in the University, have computed the following elements and ephemeris of Comet *e*, 1899 (GIACOBINI):—

OBSERVATIONS.

1899 G. M. T.	α	δ
October 2.6758	$16^h\ 32^m\ 59^s.7$	$-4°\ 12'\ 18''$
October 3.6378	16 34 22.1	−3 53 35
October 4.6292	16 35 46.7	−3 34 40

ELEMENTS.

$$T = 1899 \text{ July } 25.31196 \text{ G. M. T.}$$

$$\left.\begin{array}{l} i = 90°\ 49'\ 58'' \\ \Omega = 279\ \ 54\ \ 49 \\ \omega = 327\ \ 26\ \ 20 \end{array}\right\} 1899.0$$

$$\log q = 0.128376$$

$$\text{O-C:}\ \Delta\lambda \cos\beta = -1''.5;\ \Delta\beta = -0''.1$$

CONSTANTS FOR THE EQUATOR OF 1899.

$$x = [9.365813_5] \sin(62°\ 11'\ 36'' + v) \sec^2 \tfrac{1}{2} v$$
$$y = [0.123290] \sin(213\ \ 33\ \ \ 3 + v) \sec^2 \tfrac{1}{2} v$$
$$z = [0.126916] \sin(304\ \ 16\ \ 30 + v) \sec^2 \tfrac{1}{2} v$$

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* BREWSTER; "Martyrs of Science."

† Communicated by the Director of Students' Observatory, University of California.